A theoretical study of heavy ion collisions and related dynamical aspects

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Introduction

Complete fusion is a process in which a composite system is formed after amalgamation of target and projectile giving rise to the formation of fully equilibrated compound nucleus (CN). When two nuclei come together, they experience a long range electrostatic Coulomb force of repulsion by virtue of their charges in addition to the short range attractive nuclear force. The interplay between these two forces form a interaction/fusion barrier with an appropriate fusion pocket. To describe the nuclear interactions at both microscopic/macroscopic level, the theoretical models play very constructive role. In this work, both kind of nuclear potentials are discussed, one obtained from Blocki *et al.* [1] potential based on phenomenological picture and other using energy density formalism (macro-microscopic method) [2] which use the density dependent Skyrme interactions [3].

The main motive of this work is to address the excitation energy, angular momentum, deformation and orientation effects associated with the formation and disintegration of compound nucleus in low energy heavy ion induced reactions. To account the compound nucleus fusion process, Wong formula [4] and ℓ-summed Wong formula [5] are applied and for the decay of compound nucleus, the dynamical Cluster-decay Model (DCM) [6] is used.

Calculations and Results

Firstly, we intended to analyze the entrance channel dependence in view of ^{16}O+^{184}W, ^{19}F+^{181}Ta and ^{30}Si+^{170}Er reactions forming ^{200}Pb* compound nucleus, addressed respectively using Wong and DCM approaches. The calculations are carried out using with both the spherical and quadrupole (β_2) deformed choices of nuclei. It is observed that, the Wong formula overestimates the data for ^{19}F- and ^{30}Si- induced reactions, however underestimate excitation function of ^{16}O-induced reaction. While its extended version, *i.e.* the ℓ-summed extended Wong model, fits the experimental fusion cross-section nicely for the ^{19}F+^{181}Ta and ^{30}Si+^{170}Er channels, however inadequate to address the fusion data at few energies for ^{16}O+^{184}W reaction. The underestimation of data persists even after the inclusion of deformation effects and might be associated with the contribution of some non-compound nucleus (nCN) component. This lead us to conclusion that, the formation of ^{200}Pb* compound nucleus seems to depend on the choice of incoming channel. Apart from this, entrance channel effects are further explored in the decay path of ^{200}Pb* using DCM. An interesting result is that, although, the overall decay pattern of compound nucleus ^{200}Pb* seems similar for all the chosen reactions though some signature of variations are observed in fission and intermediate mass fragment (IMF) region for the deformed fragmentation process. It suggests the importance of deformation and orientation in the formation as well as in the decay of ^{200}Pb* CN.

The entrance channel effects are further examined in the decay of lower mass nuclei such as ^{76}Kr and ^{92}Zr formed via ^{16,18}O induced reactions. The role of iso-spin and deformations is also explored by analyzing the decay pattern of various Zr-nuclei ($^{86-92}$Zr*). It is observed that the behavior of fragmentation potential gets influenced with inclusion of deformation effects as different structural variations are obtained for spherical and deformed choices.

Next, the role of rotational energy component is tested in the dynamics of two isotopes

of Rn compound nuclei i.e. ^{214,216}Rn* formed respectively via ^{16,18}O+^{198}Pt channels using the sticking I_S and non-sticking I_{NS} limits. It is observed that, the barrier height (and corresponding position) and the preformation paths of chosen systems change significantly while going from I_{NS} to I_S approach and also depend on the deformation and orientation of nuclei. The DCM calculated ER cross-sections find nice agreement with the experimental data within both the sticking or non-sticking limits of interaction. This is true for spherical as well as deformed choice of fragmentation. Whereas, ff data is fitted within I_S limit only specially after inclusion of higher order deformation effects.

Finally, the nuclear dynamics and related deformations effects are investigated using different nuclear interaction potentials. Firstly, the role of deformations and orientations is examined in terms of spin-orbit density dependent part V_J of nuclear potential (V_N=V_P+V_J) obtained within semi-classical Skyrme Energy Density Formalism (SEDF). For the purpose, $^{24-54}$Si+^{30}Si reactions are considered with spherical target ^{30}Si and projectiles $^{24-54}$Si having prolate and oblate shapes. The calculations suggest that, Si-nuclei with β_2 <0 form most compact configuration at $(0^0, 180^0)$, which further changes to $(90^0, 180^0)$ for nuclei with β_2 >0. The possible role of spin-orbit potential on barrier characteristics such as barrier height, barrier curvature and subsequently on the fusion pocket is also probed. The effect of spin-orbit interaction potential is further explored by considering a two nucleon transfer process by employing various entrance channels such as ^{23}Na+^{49}V,^{25}Mg+^{47}Ti,^{27}Al+^{45}Sc,^{29}Si+^{43}Ca and ^{31}P+^{41}K, all forming the same compound system ^{72}Se*, using SIII-Skyrme force. It is observed that, for spherical nuclei, the spin-orbit density part V_J of nucleon-nucleon potential remains unaffected with the transfer of two nucleon from target to projectile, however it shows notable variation in magnitude after inclusion of deformation effects. Likewise, deformations play important role in spin-orbit density independent part V_P, as the fusion pocket start appearing, which otherwise diminish for the spherical case. Further, the effect of increase in N/Z ratio of Se nucleus is inspected in view of V_J as well as V_P and results are compared with transfer channels. In addition to this, the decay path of ^{72}Se* nucleus formed in ^{27}Al+^{45}Sc reaction is investigated within framework of DCM, where the nuclear proximity potential is obtained by both SEDF and proximity pocket formula. The contribution of V_J is also estimated in ER excitation functions of ^{27}Al+^{45}Sc reaction using single (W_0) and double (W_0 and W_0') spin-orbit parameters in view of SIII (W_0 = W_0'), SkI2 (W_0 = W_0'), SkI3 (W_0'=0) and SkI4 ($W_0 \neq W_0'$) Skyrme forces. It is observed that the ER cross-sections deviate from experimental data by $\sim$ 56 mb for SIII, $\sim$ 76 for SkI2, $\sim$ 62 for SkI3 and $\sim$ 120 mb for SkI4 force, when V_J is excluded. The decrement in ER cross-section is larger for SkI4 force as compared to other Skyrme forces, enforcing the effect of double spin-orbit parameter.

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